深圳大学
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Physical Internet Enabled Bulky Goods Delivery and Pick Up Solution in City Logistics

Author：Luo Hao, Tian Siyu, Yang Xuan

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01 Research Background

Bulky Goods Delivery in City Logistics

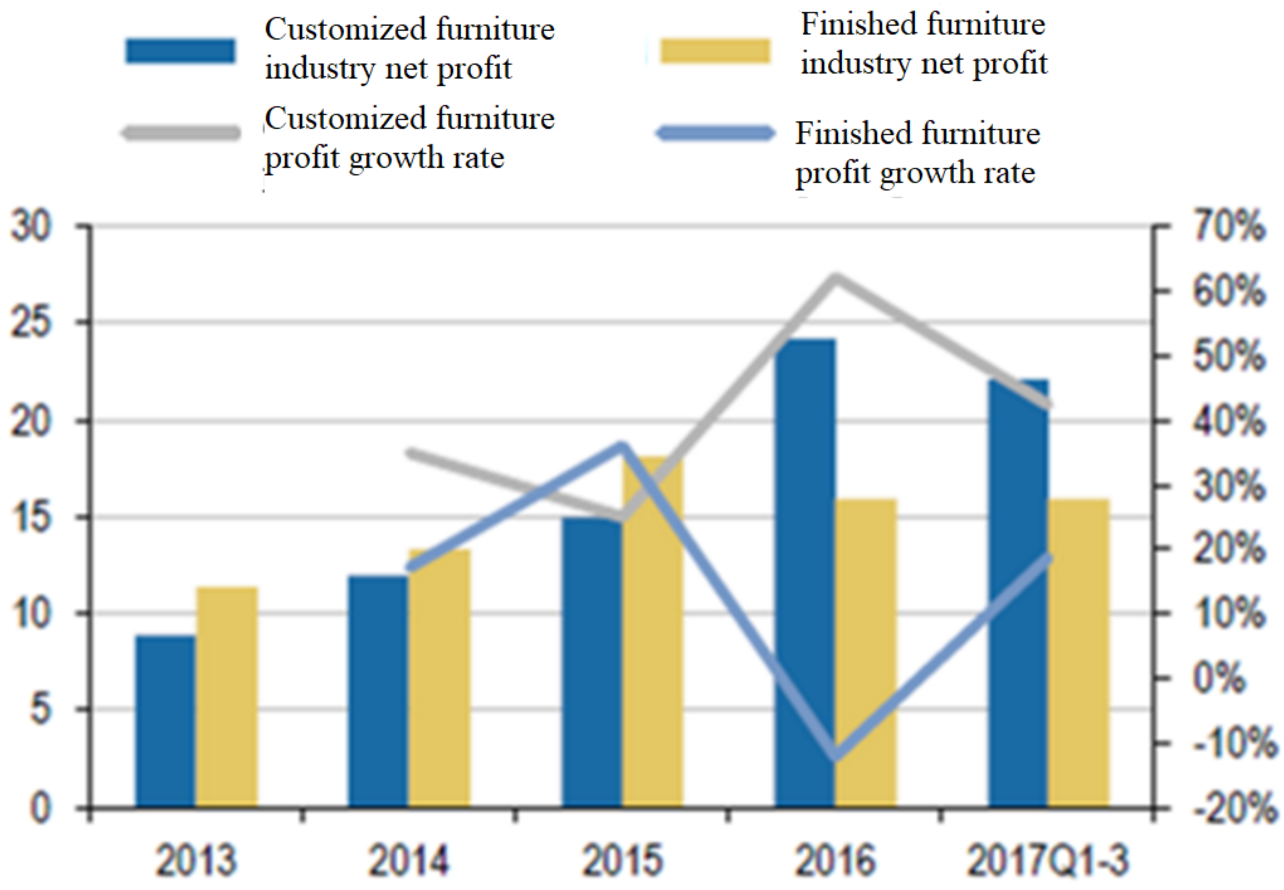
Fitness Equipment

Furniture

Musical Instruments

Household Appliances

Market penetration of Customized furniture industry



Comparing the accumulated net profit (100 million RMB) and growth rate of customized and finished furniture in China

Source: http://www.chyxx.com

Furniture is one of the typical products in bulky goods delivery. With the upgrading of consumption structure and the O2O commercial technology, customers are not satisfied with a standardized product. They are willing to participate in the design and manufacturing process. Furniture customization industry is growing as more and more promising one.

SPZP-Customized Furniture in China

尚品宅配
ORDER YOUR LIFE

- Funded in 2004
- 800+ Chain stores in Beijing, Shanghai, Guangzhou, Wuhan
- 2017 total revenue 5.3 Billion (RMB) rise by 32.23 % over the same period of 2016
- 100+ Whole House Furniture Customization orders per Day
- Largest Furniture Database + House layout Database + House Design Database

02 Business Challenges

SPZP-Furniture Delivery

Manager of SPZP: ‘If nothing changes, the logistics cost will exceed their revenue’

Characteristics of Customized Furniture Industry

01

Multiple Components

Most of the product form is board–shape furniture components and consist of a large number of metal accessories.

02

Long waiting time

The long on-site material handling time leads to long waiting time to the vehicle.

03

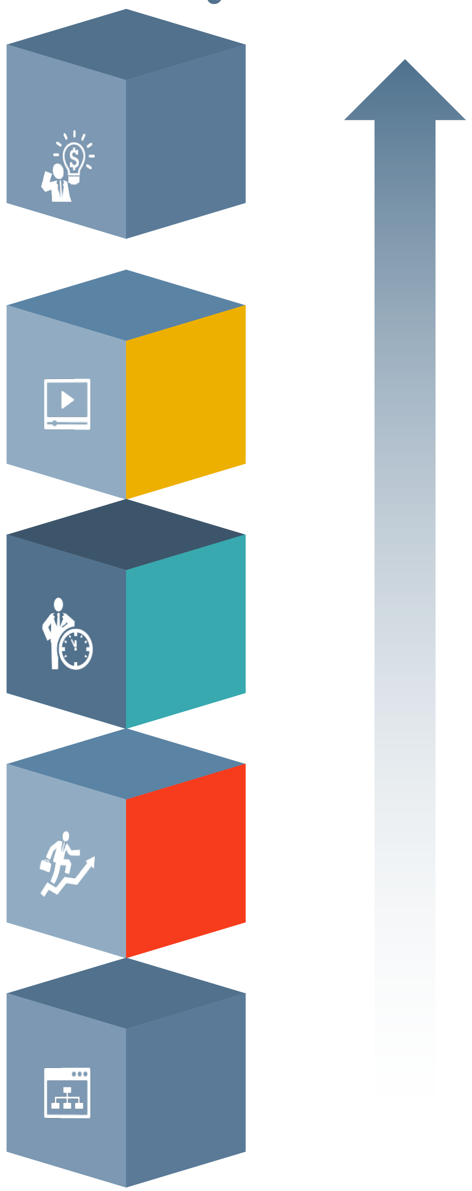
Unique piece

Since the furniture is customized, therefore pieces of the customized furniture were only produced once.

04

High damage rate

The repeatedly loading and unloading operation may lead to product damage.



Pain Points of Customized Furniture Delivery

Heavy Workload of Material Handling

- 300+ pieces of components / order
- Unloading from the truck one by one
- Moving from unloading point to room
- Elevator may not available!!

Unclear Responsibility for Operators

- Truck driver may need to do the material handling work.
- Truck driver may need to wait during the material handling.
- Material handling operator has to go with driver

High Risk of Product Damage

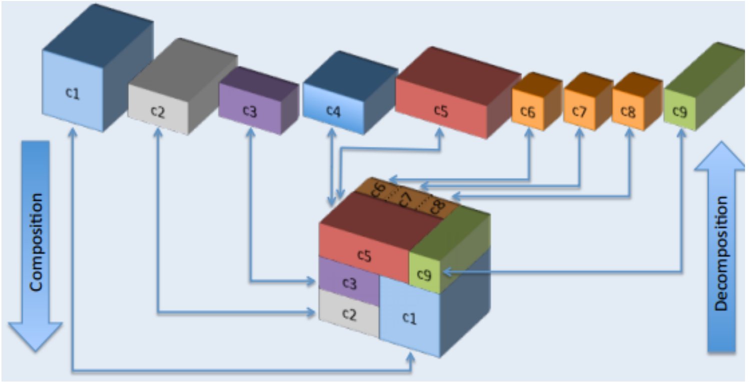
- Many times loading and unloading work
- Components without any protection
- One piece damage, whole order delay
- Long time for remanufacturing

Complicated Human and Vehicle Resource Planning

- Order consolidation Planning
- Truck loading planning
- Delivery route planning
- Operator assignment planning

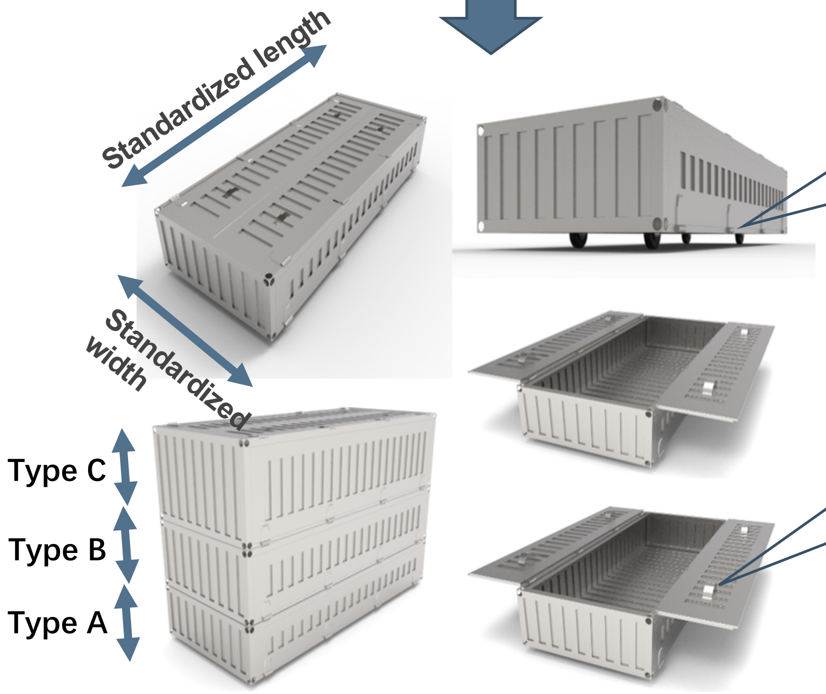
03 Solution Methodology

PI Container

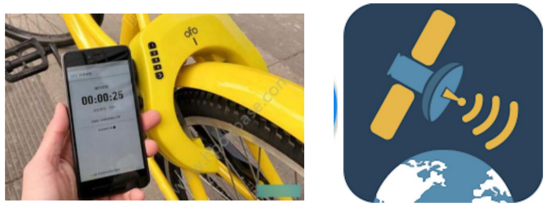


History Data of Order Size

Container Sizing Optimization



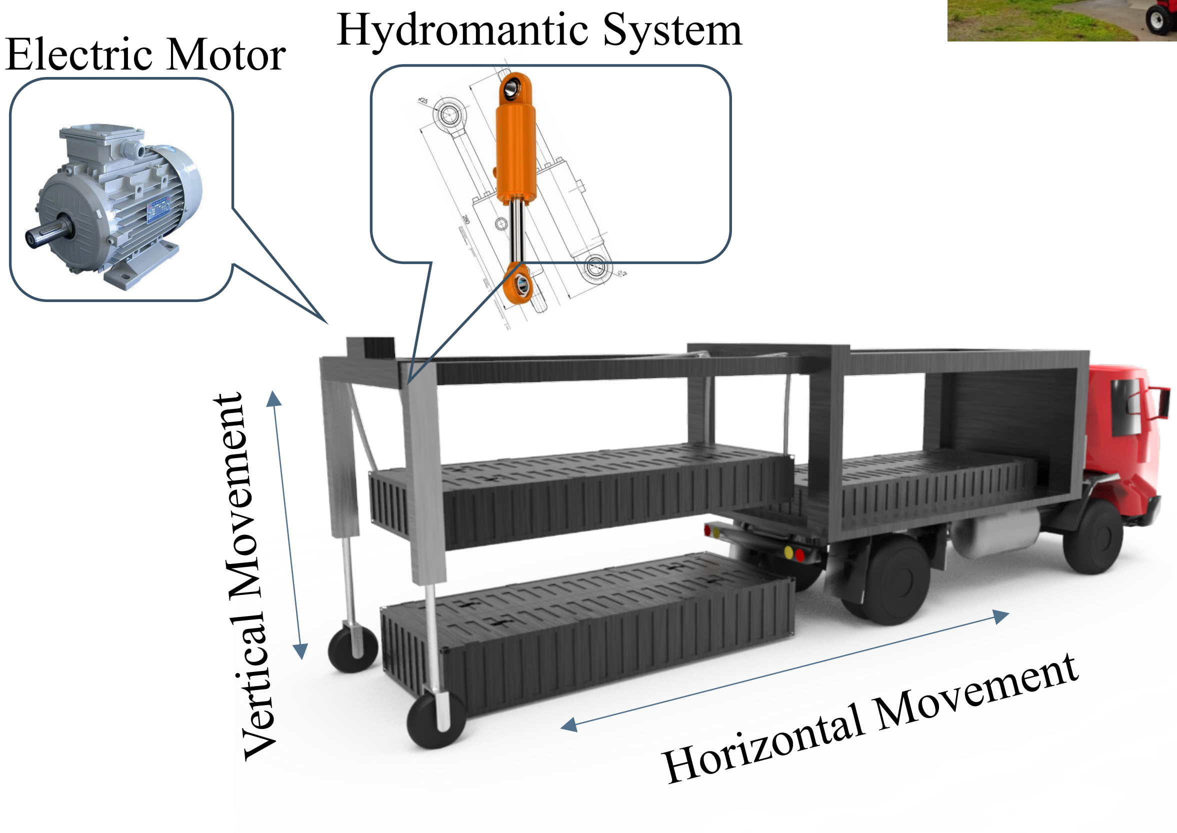
Universal wheel Design for on-site movement



NB-IoT GPS

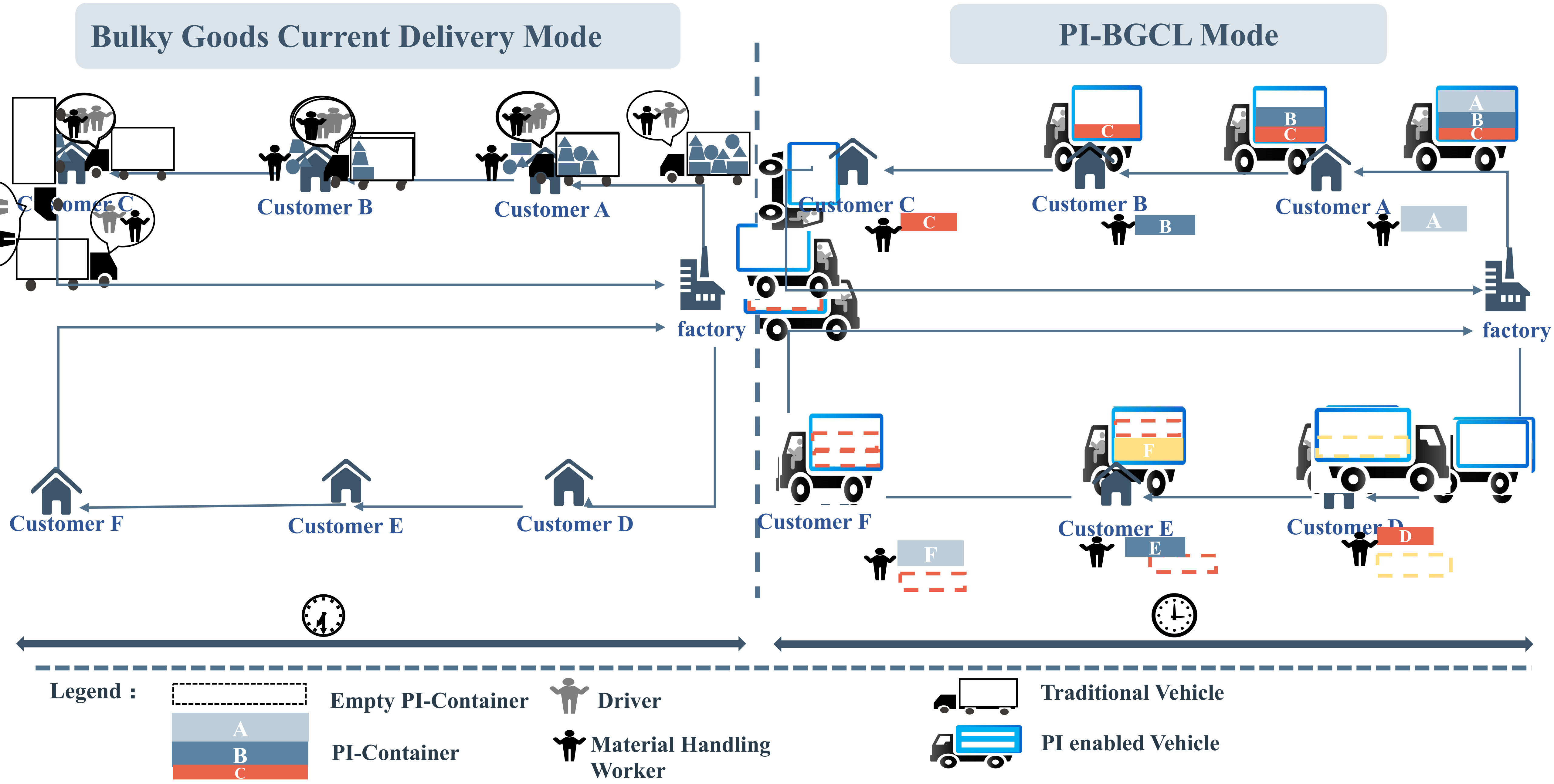
IoT Locker with LBS (location base service) And Mobile App Control

PI Vehicle



Transpiration status → Loading/Unloading status → Unloading Finished

Physical Internet enabled Bulky Goods City Logistics Mode



04 Mathematical Model

Problem Formulation—— Assumption

1) Customer locations and demands are known in advance;
2) Vehicles are of an identical capacity which cannot be violated at any time;
3) Split delivery is not allowed, i.e. a customer can be served with only one vehicle visit;
4) The commodities are transported by PI-containers with three different sizes: large, medium, and small;
5) A porter's salary is based on the amount of goods he totally carried
6) In the PI-BGCL mode, empty containers must be collected and transported to the distribution center by the end of each day.

Problem Formulation—— Notation

N	total number of customers which need to pick up empty container by delivery $P=\{1,...,n\}$
N'	total number of customers which has remaining containers need to pick up separately $P'=\{n+1,...,2n\}$
M	total number of customers which need to delivery merchandise $D=\{1,...,m\}$
V	all the vertices by delivery vehicle $V=P\cup D$
K	the set of vehicle's number, $K=\{1,2,...k\}$
T	number of days of the period
Q	the rated capacity of truck
i,j,f,g	customer vertices, distribution center $i=0$
$[t_0,t_e]$	the time window of distribution center
t_{ij}	the travel time from vertex i to j
L_i^k	driver's waiting time of vehicle k arrives at vertex i, which equals to the service time of material handling worker at vertex i.
$d_i^{k,r}$	the delivery demand of vehicle k at vertex i, $r\in\{S,M,L\}$
$q_i^{n,r}$	the pick up remaining empty container demand of vehicle n at vertex i
$P_{i,j}^{r,k}$	load of vehicle k of resource r after leaving vertex i before visiting vertex j
β	the petrol fee of each vehicle per minute
δ	the fixed cost of each vehicle k
α	logistics service fee for each item

$$x_{ij}^{kl}=\begin{cases}1, \text{if } arc(i,j) \text{ is traversed by vehicle } k \text{ on day } l\\ 0, \text{else}\end{cases}$$

$$y_i^{kl}=\begin{cases}1, \text{if vehicle } k \text{ pick up or delivery container at vertex } i \text{ on day } l\\ 0, \text{else}\end{cases}$$

Mathematical model

Objective function: To maximize net income per unit time

PI-BGCL mode

Total revenue — Fuel cost — fixed cost of vehicle — Total travel time

$$\text{Max } Z=\left\{\frac{\alpha\sum_{l=1}^{T}\sum_{i,j\epsilon D}\sum_{m\epsilon K}x_{ij}^{ml}d_{i}^{ml}-(\beta\sum_{l=1}^{T}\sum_{m\epsilon K}\sum_{i\epsilon V\cup P'}\sum_{j\epsilon V\cup P'}x_{ij}^{ml}t_{ij}+\delta\sum_{l=1}^{T}\sum_{m\epsilon K}\sum_{i\epsilon V\cup P'}x_{0i}^{ml})}{\sum_{l=1}^{T}\sum_{m\epsilon K}\sum_{i\epsilon V\cup P'}\sum_{j\epsilon V\cup P'}x_{ij}^{ml}t_{ij}}\right\}$$

Subject to :

$\sum_{k\in K}\sum_{i\epsilon V\cup P'}y_{i}^{kl}=1$	$\forall l\in T$	(2)
$\sum_{m\epsilon K}\sum_{i\epsilon V\cup P'}\sum_{j\epsilon V\cup P'}x_{ij}^{ml}t_{ij}=\sum_{k\epsilon K}\sum_{i\epsilon V}\sum_{j\epsilon V}x_{ij}^{kl}t_{ij}+\sum_{n\epsilon K}\sum_{f\epsilon P'}\sum_{g\epsilon P'}x_{fg}^{nl}t_{fg}$	$\forall n,k\in K;\forall l\in T$	(3)
$\sum_{k\in K}\sum_{j\in V}x_{ij}^{kl}=1$; $\sum_{n\in K}\sum_{g\in V}x_{fg}^{kl}=1$	$\forall i,j\in V;\forall f\in P';\forall l\in T$	(4)
$\sum_{i,j\epsilon V}x_{ij}^{kl}-\sum_{i,j\in V}x_{ji}^{kl}=0$; $\sum_{f,g\epsilon P'}x_{fg}^{nl}-\sum_{f,g\epsilon P'}x_{gf}^{nl}=0$	$\forall n,k\in K;\forall l\in T$	(5)
$\sum_{j\in V}x_{0j}^{kl}=\sum_{j\in V}x_{j0}^{kl}\leq 1$; $\sum_{g\in P'}x_{0g}^{nl}=\sum_{g\in P'}x_{g0}^{nl}\leq 1$	$\forall n,k\in K;\forall l\in T$	(6)
$t_0\leq\sum_{i\epsilon V}\sum_{j\epsilon V}x_{ij}^{kl}t_{ij}\leq t_e$; $t_0\leq\sum_{g\epsilon P'}\sum_{g\epsilon P'}x_{fg}^{nl}t_{fg}\leq t_e$	$\forall i,j\in V,\ \forall f,g\in P',\forall n,k\in K;\forall l\in T$	(7)
$\sum_{k\epsilon K}\sum_{i,j\epsilon P}x_{ij}^{k}d_{il-1}=\sum_{n\epsilon K}\sum_{f,g\epsilon P'}x_{fg}^{n}q_{fl}+\sum_{k\epsilon K}\sum_{r\epsilon R}\sum_{i,j\epsilon P}x_{ij}^{k}(P_{i,j,l}^{r,k}-P_{0,i,l}^{r,k}+d_{il})$	$\forall n,k\in K;\forall l\in T$	(8)
$\sum_{i\epsilon V}d_{i}^{kl}\leq Q$	$\forall i\in V,\forall k\in K;\forall l\in T$	(9)
$q_{f}^{nl}\leq Q$	$\forall f\in P',\forall n\in K;\forall l\in T$	(10)
$\sum_{r\epsilon R}x_{ij}^{kl}P_{i,j}^{r,k}-\sum_{r\epsilon R}x_{0i}^{kl}P_{0,i}^{r,k}+d_{i}^{kl}\leq Q$	$\forall i,j\in V,\forall k\in K;\forall l\in T$	(11)
$\sum_{r\epsilon R}x_{ij}^{kl}P_{i,j}^{r,k}\leq Q$	$\forall i,j\in V,\forall k\in K;\forall l\in T$	(12)
$\sum_{r\epsilon R}x_{fg}^{kl}P_{f,g}^{r,n}\leq Q$	$\forall f,g\in P',\forall n\in K;\forall l\in T$	(13)

Current Delivery mode

Total revenue — Fuel cost — fixed cost of vehicle — Total travel time

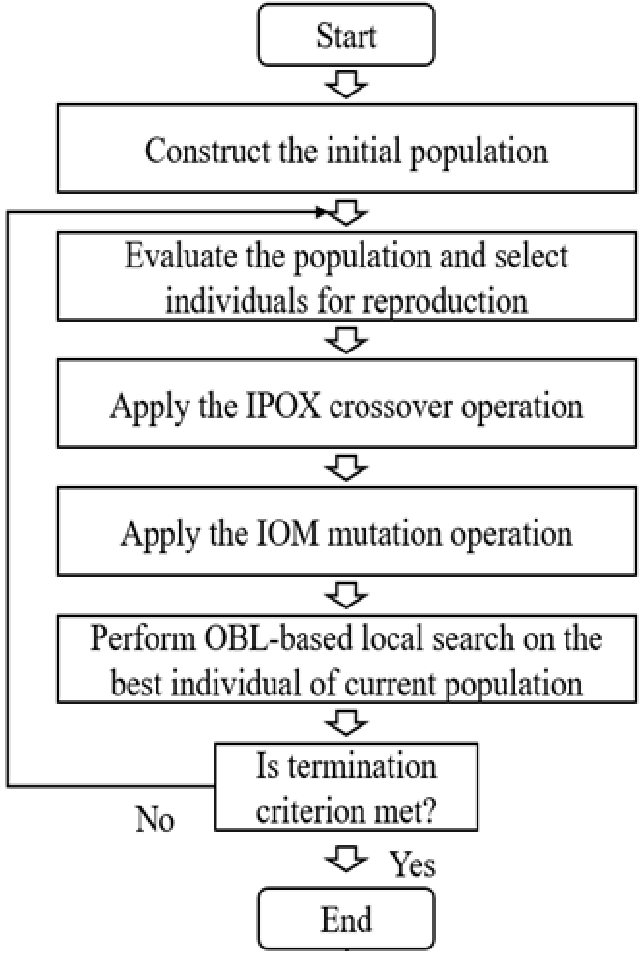
$$\text{Max } Z=\left\{\frac{\alpha\sum_{l=1}^{T}\sum_{i,j\epsilon D}\sum_{k\epsilon K}x_{ij}^{kl}d_{i}^{l}-(\beta\sum_{l=1}^{T}\sum_{k\epsilon K}\sum_{i\epsilon D}\sum_{j\epsilon D}x_{ij}^{kl}t_{ij}+\delta\sum_{l=1}^{T}\sum_{k\epsilon K}\sum_{i\epsilon D}x_{0i}^{kl})}{\sum_{l=1}^{T}\left(\sum_{k\epsilon K}\sum_{i\epsilon D}\sum_{j\epsilon D}x_{ij}^{kl}t_{ij}+\sum_{k\epsilon K}\sum_{i\epsilon D}L_{i}^{kl}\right)}\right\}$$

Subject to :

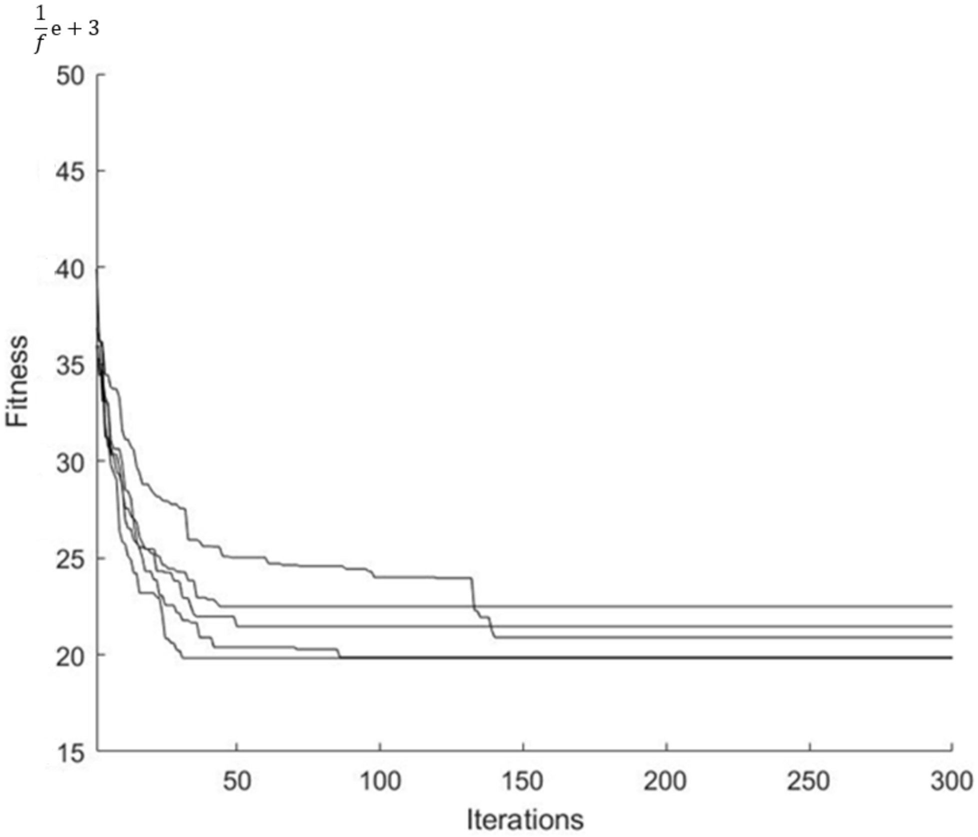
$\sum_{k\epsilon K}\sum_{i\epsilon D}y_{i}^{kl}=1$	$\forall l\in T$	(2)
$\sum_{k\epsilon K}\sum_{j\epsilon D}x_{ij}^{kl}=1$	$\forall i\in D;\forall l\in T$	(3)
$\sum_{i,j\epsilon D}x_{ij}^{kl}-\sum_{i,j\epsilon D}x_{ji}^{kl}=0$	$\forall k\in K;\forall l\in T$	(4)
$\sum_{j\epsilon D}x_{0j}^{kl}=\sum_{j\epsilon D}x_{j0}^{kl}\leq 1$	$\forall k\in K;\forall l\in T$	(5)
$\sum_{i\epsilon D}\sum_{j\epsilon D}x_{ij}^{kl}d_{i}^{l}\leq Q$	$\forall k\in K;\forall l\in T$	(6)
$t_0\leq\sum_{i\epsilon D}\sum_{j\epsilon D}x_{ij}^{kl}t_{ij}+\sum_{i\epsilon D}L_{i}^{kl}\leq t_e$	$\forall k\in K;\forall l\in T$	(7)

Hybrid meta-heuristic algorithm – GA_VNS

The flowchart of GA_VNS in this problem



The convergence of GA_VNS for different scale problems



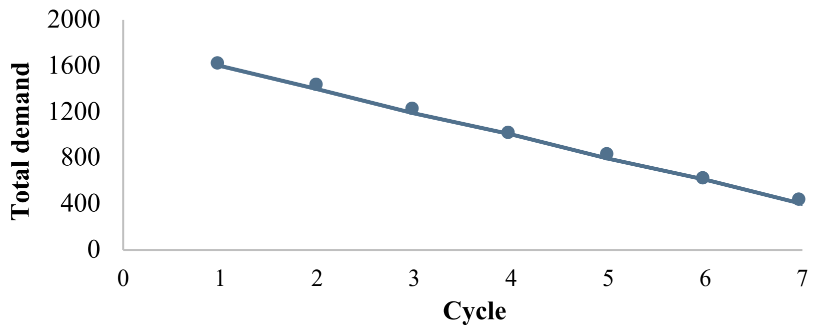
05 Computational Results and discussion

Computational Results

1. The impact of demand decreases on two delivery modes

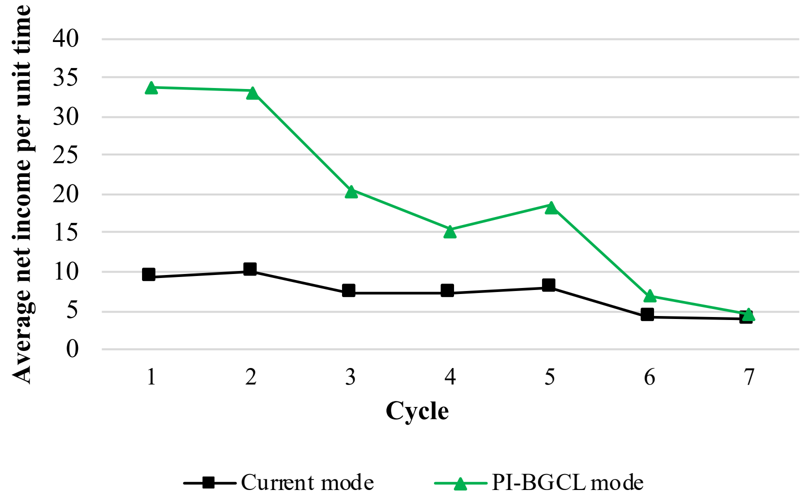
Computational process

1. Generate a 7-cycle total demand with a gradual decreasing rule.
2. Randomly generate 10 sets of demand allocation schemes under each total demand.
3. Calculate the average net income per unit time (*AZ*) for both modes.



Computational Results

1. As demand continues to decrease, the average net income per unit time decline in both modes.
2. The graph of current mode shows a slight decrease, but the figure of PI-BGCL mode dropped dramatically.
3. The advantage of the PI-BGCL mode to the current mode disappears as the demand declines.



Computational Results

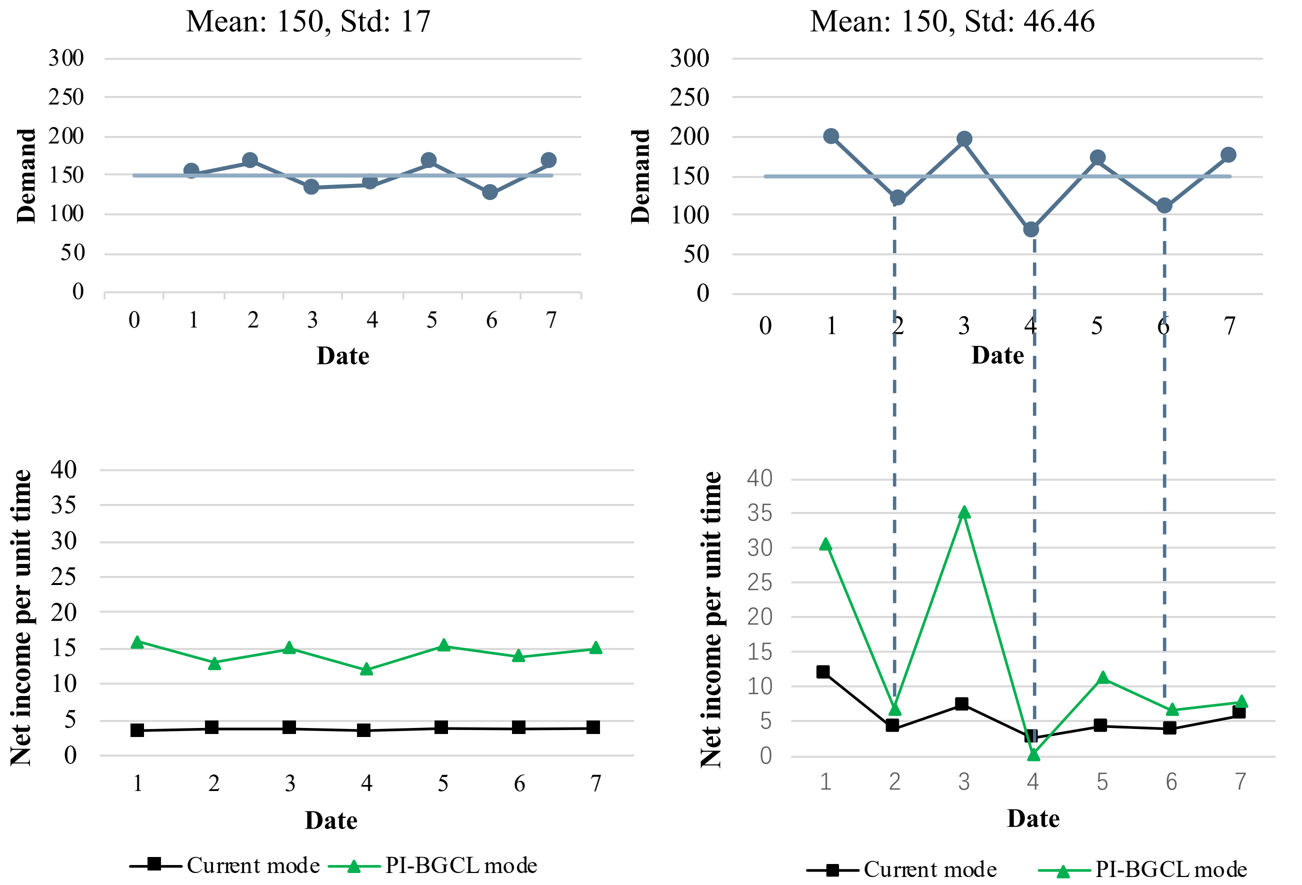
2. The impact of fluctuations in demand on two modes in a single cycle

Computational process

1. Generate two sets of demand with the same mean but different standard deviations in a cycle with 7 days
2. Calculate the net income per unit time for both modes.

Computational Results

1. When demand fluctuates slightly, impact on both modes is weak.
2. When demand fluctuates significantly, the two modes start to fluctuate, and the fluctuation of the PI-BGCL mode is more significant than the current mode.
3. When the demand for a day is much smaller than that of the previous day, the net income per unit time of the PI-BGCL mode is lower, sometimes even lower than the current mode.



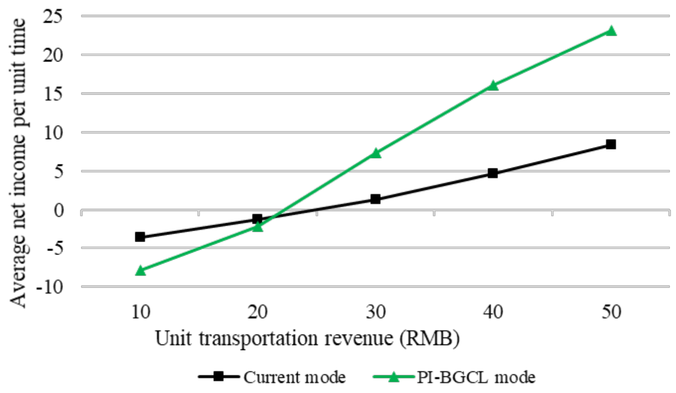
Computational Results

3. The impact of cost and benefit parameters on the results

Computational process

1. A total of 125 (5*5*5=125) test problems are randomly generated.
2. All problems are examined by covering possible values of the unit freight rate (*rp*), fuel cost per kilometer (*fc*) and fixed vehicle cost (*vc*).
3. For the proposed meta-heuristic, 10 independent replications are first performed on each of the test problem, and the best value over these 10 runs are accordingly obtained.

Figure 1. Average net income per unit time with different unit freight rate



Computational Results

1. As *rp* increases, the *AZ* of the two modes increase and the junction of two graph is in *rp* ∈ (20, 30).
2. As *fc* increases, the *AZ* of the two modes decrease and the junction of two graph is in *fc* ∈ (1.3, 1.8).
3. As *rp* increases, the *AZ* of the two modes decrease and the junction of two graph is in *vc* ∈ (170, 200).

Figure 2. Average net income per minute with different fuel cost

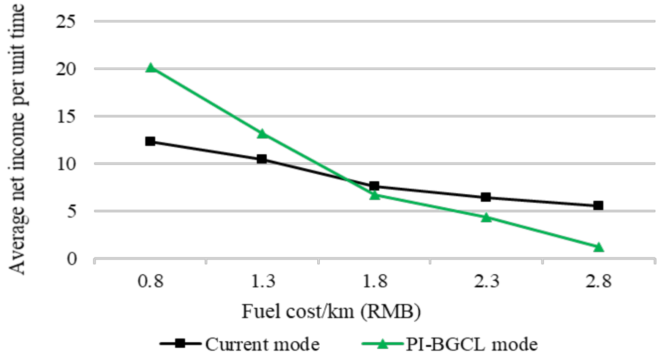
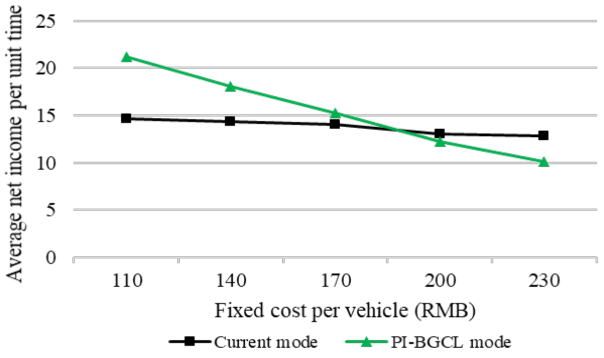


Figure 3. Average net income per minute with different fixed vehicle cost



Managerial implications

From above analysis, several managerial implications can be derived as follows based on the above computational results:

1. With customer demands increase, PI-BGCL mode can help the company to improve their income and enhance their competitiveness.
2. Significant fluctuations in customer demand will cause revenue declines in PI-BGCL mode.
3. Compared with current mode, PI-BGCL mode has an advantage in improving enterprise's profitability by improve the freight rate.
4. The PI-BGCL mode is more sensitive to the changes of fuel cost and fixed vehicle cost compare to current mode. Therefore excessive cost will cause the profitability of PI-BGCL mode to deteriorate.

Conclusions

1. The specific features of a customized furniture enterprise has been studied and the pain points of customized furniture delivery has been summarized.
2. Proposed an effective solution for bulky goods city logistics based on PI concept: PI-BGCL mode.
3. Designed a meta-heuristic algorithms (GA-VNS) to solve the problem of income optimization.
4. The applicability of PI-BGCL mode under different parameters has been analyzed.

Future Works

Future studies will focus on making the proposed solutions more practical.

- How to generalize the results of such a small sample to a broader context.
- PI-Container and PI Vehicle Development

Thank You for your attention!

Email: yangxuan20161@email.szu.edu.cn